21. HELICOPTER VISUAL AID SYSTEM

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SUMMARY

The results of an evaluation of Police Helicopter effectiveness revealed a need for improved visual capability. A JPL program developed a method that would enhance visual observation capability for both day and night usage and demonstrated the feasibility of the adopted approach.

This approach, the Helicopter Visual Aid System, incorporated three interesting mechanisms as solutions to design and development problems. These mechanisms contributed greatly to the successful operation of the Helicopter Visual Aid System.

INTRODUCTION

Background

Recently many law enforcement agencies have integrated helicopters into their patrol activities, and the trend toward their use is continuing to increase on a national scale. Experiences with these aerial patrols led to recognition of the limitations of the basic observation system. The initial system consisted of the helicopter, the observer, and sometimes minimal visual aids such as binoculars or a camera. This minimal amount of support equipment for the full range of police missions, conducted both at night and during the day, limits the potential value of the helicopter system. Many attempts have been made to adapt equipment designed for other purposes to use on police helicopter patrols. Little effort has been made, however, to design equipment specifically for the police helicopter in its performance of the patrol function.

In response to this need, the Jet Propulsion Laboratory has developed a Visual Aid System for helicopters that is based on a set of requirements derived from law enforcement agencies (Ref. 1).

Problem Definition

The initial definition of the problem was based upon a previous Civil Systems task at JPL. In this task, the Los Angeles Police Department's helicopter patrol program was evaluated, with one element of this effort being the assessment of various means by which patrol effectiveness could be increased. A major item identified was improved visual capability.

To confirm some of these observations, and to provide a broader base of understanding of the range of missions and their requirements, a nationwide survey was conducted involving ten law enforcement organizations. This survey confirmed the pressing need for improved visual capability.

From this, the functional requirements for a visual aid system were established to be:

(1) An increased field-of-view, coupled with the capability to see at night without visible illumination. Minimum resolution should be equivalent to that of the unaided eye under conditions of daylight illumination.

(2) An improved capability to see during normal conditions of daylight illumination through an increased field-of-view as above and with increased resolution.

(3) Evidence-gathering capability through airborne photography.

Requirements and Constraints

Based on the functional requirements, physical constraints and technical requirements were established for a visual aid system and are outlined below.

(1) Physical Constraints: Bounded by the characteristics of the Bell 47 G-5 helicopter, chosen to be the test vehicle.

(2) Mode of Operation: Daytime operation under ambient light conditions and nighttime operation using either visible illumination or non-visible infrared illumination.

(3) Fields-of-View: The field-of-view centerline shall be pointable from the horizon to at least 45° below the horizon and from a forward position to at least 90° right azimuth. In addition, it shall be capable of variable magnification.

(4) Visual Resolution: Daylight resolution capable of resolving line pairs on a 1951 Air Force resolution chart, which are separated by 50 μrad and which have typical brightness values equal to or greater than 1000 ft-L. At night, have the capability to distinguish line pairs separated by 250 μrad and have typical brightness due to ambient illumination of 0.001 ft-L.

(5) Display Characteristics: The image shall be erect and non-reverted and shall have a minimum brightness of 1 ft-L. It shall also incorporate an indicator that shows the orientation of the line of sight relative to the vehicle. A similar indicator shall be provided for the pilot.

(6) Searchlight: The searchlight shall be slaved in azimuth and elevation to the turret subassembly and shall be capable of remote control by the observer. The capability shall exist to remotely control the filter elements required for both visible and covert illumination of a target.

SYSTEM DESCRIPTION

The breadboard Visual Aid System consisted of five modular elements: the optical turret, the optical display, the searchlight, the control console and the auxiliary generator.

The Visual Aid System optics and electro-optics were packaged into two separate modules; the turret, located underneath and forward on the "chin" of the vehicle and including the front objective lens and turning mirrors, and the display that contained the balance of the optics. A flexible, image-carrying fiber-optics bundle connected the two modules. A description of the optics, keyed to Fig. 1, is presented below.

One of the two objective lens (3 and 4) alternately provided a focused image upon the end of the fiber-optics bundle (7), the selection depending upon the orientation of the switching mirror (6). Each of the objective lenses "looked out" through a flat glass window (1). Turning mirrors (2) and windows were coupled in rotating housings to form optical scanning heads. These heads are mechanically coupled together and rotate as shown about the common axis of the objective lenses providing an elevation scan. Rotation of the entire turret about the centerline shown at the left of Fig. 1 represents an azimuth scan.

Objective lens (3) and (4) were 21-inch and 3-inch focal length, providing 7-power and one-power magnification.

The four-foot-long fiber-optics bundle (7), comprised of 3 million flexible optical conduits, each 10μ in diameter, transmits the image from the turret to the display without transmitting mechanical motions from one to the other.

The first relay lens pair (8) collected the visible or infrared light from the fiber-optics bundle and reformed the image at the photocathode of the intensifier (11), or at the field lens (12), for further relay through the display module.

The filter wheel (10) contained, in one position, a multilayer filter to pass near-infrared and exclude visible light and, in a second position, a clear piece of glass of appropriate thickness to correct for visible light focal length of the first relay lens pair (8).

The image intensifier (11) was a cascaded three-stage, electrostatically imaged intensifier with photocathode and phosphor screen diameters of 40 mm each. Light gain through the tube is typically increased by a multiple of 100,000.

Relay lens (13) was mounted in a turret with the image intensifier and could be rotated into position to relay a visible image from the first relay pair (8). Field lenses (12) were located at the input and exit image locations to minimize vignetting.

Display switching mirror (14) had two operating positions: one directed light from the image intensifier or second relay lens to a 35 mm recording camera (16) and the other, to a projection lens (17), which forms the final image at the viewer end of the display.

The projections lens (17), the viewing field lens (23) and pupil splitter (22) provided a pair of exit pupils imaged approximately 16 in. beyond the viewing field lens. The exit pupils were approximately 1 in. in diameter and spaced on center by an average adult interpupillary separation of a little less than 3 in. It was at this location that an observer positioned his eyes to look into the display.

Items (18) and (19) are a light-emitting diode (LED) and a projection lens, respectively, which are incorporated into a position indicator. The LED was mounted onto a torquer-driven assembly which was gimballed to allow reproducing the azimuth and elevation angles of the turret assembly. The combining mirror allows an image of the LED to be formed at the pupil splitter and viewing field lens. The red dot was seen with both eyes as superimposed upon the presented scene.

Optical Turret

The major functions of the optical turret illustrated in Fig. 2 were to provide azimuth and elevation scanning for the objective lenses; focusing of the optics; selection of magnification; a mechanization to maintain the horizon level at the display; image motion stabilization; support structure to maintain alignment of the elements; and a housing to provide a protective enclosure against weather conditions.

Servo-driven, the turret rotated in azimuth through 180°, from straight forward clockwise to straight backward. In elevation, the pointing limits of 0° (horizon) to 75° below horizon were achieved. The skew rate of the turret was measured to be 22.5°/s in azimuth and 26°/s in elevation.

The details of image motion stabilization combined three techniques. First, vibration isolators were used between the helicopter and the suspended portion of the turret. Second, large stabilizing gyros were added to the isolated member to increase the rotational inertia. Third, rate gyros were mounted on the turret to sense angular motion and, through the control system, the elevation and azimuth servos were driven to directly compensate for that motion.

Magnification changes were accomplished by rotating a diagonal mirror to direct the optical axis from a one-power (1X) objective lens to the seven-power (7X) objective lens. Accurate indexing was achieved through a motor-driven Geneva mechanism. The development of this mechanism is one of the subjects of further discussion later in this paper.

One feature that is familiar to us is the level horizon at the top of a scene whatever direction we may turn our head. To help maintain orientation it was decided to present a display with the horizon at the top, which would be fixed with respect to the observer even though the helicopter should roll and pitch. The concept used in the turret utilized rotating mirrors for scanning and as a result caused unwanted image and horizon rotation that required compensation. This compensation was achieved through rotation of the fiber-optics rope in response to each of these turret functions. This fiber-optics mechanism is also the subject of additional discussion later in this paper.

Rotation of the fiber optics required a mechanism capable of summing the variables that affect image rotation. This was accomplished by utilizing a combination of summing differentials and a servo-driven phasing mechanism. The development of this mechanization is also discussed in further detail.

Optical Display

Several functions were provided in the display module. These were, principally, display of the image (day or night), conversion of infrared to visible light (night), intensification of the visible or infrared image (night), and display of the turret-pointing position indicator. Certain ancillary functions were also mechanized.

Figure 3 shows the display module mounted on a supporting stand prior to installation in the helicopter. The upright drum housed the day-night turret. The fiber-optics rope entered the display module from bottom far side as seen in this photograph. The viewing field lens is shown located in the diagonal housing at the upper left of the module.

Searchlight

The searchlight used for the breadboard Visual Aid System was the commercially available SX-16 "Nightsun" manufactured by Spectrolab of Sylmar, Cal. The light is in wide use by law enforcement agencies for nighttime airborne search and tactical operations. It has a 1600-W xenon short arc lamp that supplies 21,000 lumens in a beam that may be varied in flight from 4° to 10° in width. It is servo-driven and slaved to the look vector of the optical turret.

As procured from Spectrolab, the searchlight had either of two windows mounted in a light-baffled, air-ducted shell (Fig. 4). One was a clear window that passed essentially all visible and near-infrared radiation. The other had a multilayer interference filter that passed the near-infrared but reflected essentially all visible radiation back to the bulb. The transmission characteristics of the infrared beam reduced the visibility of the direct searchlight beam to an appearance similar to that of the helicopter running lights when viewed from a distance.

Control Console

Figure 5 is a photograph of the control console in its breadboard configuration. It was located between the pilot and observer, in a position where controls were conveniently operated by the observer's left hand. It provided control over the system as indicated by the functions on the control panel. Pointing of the turret look vector was accomplished by a control stick mounted to a floor pedestal in front of the observer.

Helicopter Installation

Installation of the Visual Aid into the police helicopter (Bell 47 G-5) is illustrated in Figure 6.

MECHANIZATION PROBLEMS

The design and development of the system required the application of several mechanisms, three of which are discussed in this text. They have been highlighted in the description of the system and will be discussed in detail below.

GENEVA MECHANISM

Background

As was pointed out, magnification changes in the optical system were accomplished by rotation of the turret switching mirror, directing the optical axis from the 1X to the 7X objective lens. Accurate indexing of this mirror was required at two discrete positions, the optical axes of the 1X and 7X lens. In addition, the mirror is coupled through a geared assembly to a fiber-optics rope. The fiber-optics rope, when twisted, exhibits a torsional spring rate, which through the geared assembly is fed back to the same mecha sm that indexes the mirror.

A motor-driven Geneva mechanism was selected for this application because of its accurate indexing characteristics. In operation, the choice of image magnification (use of 1X or 7X objective lens) is accomplished by applying DC power of selected polarity (dependent upon choice of 1X or 7X lens), to the Geneva drive motor. Upon reaching the selected index position, actuation of a micro-switch interrupts the applied power. Motor coasting, thus, overshoot of the index position, is prevented by the application of dynamic braking on the motor.

In the specific design, the Geneva driver wheel, Figure 7, is rotated by a DC motor through a double reduction spur drive.

In operation the star wheel is driven through one 90° increment for each revolution of the driver wheel. This sequence is illustrated in Figure 8.

The star wheel is directly connected to the mirror and, through a geared assembly, to the fiber-optics rope. The torsional spring rate of the rope appears (Fig. 7) as a torque on the star wheel applied in the direction of star wheel rotation.

Problem

Initially, the design and fabrication of this Geneva assembly was straightforward. When tested, both as a subassembly and later installed in the turret module (less fiber-optics rope), no operating difficulties were encountered. Upon assembly of the turret module with the display module, including the interconnecting fiber-optics rope, problems with the Geneva operation were encountered.

When actuated in one direction (1X to 7X) the Geneva operated properly. However, when operated in the opposite direction (7X to 1X), full rotational travel could not be attained and binding occurred at the beginning of travel. When the rope was disconnected, the Geneva operated properly in both directions. With the Geneva set in the 7X position, the rope was reconnected. This resulted in the reverse situation, proper operation from 7X to 1X but incomplete travel from 1X to 7X. This confirmed that restoring torque, resulting from rope torque, was causing the star wheel and driver to bind when actuated in the direction of restoring torque. Installing the rope with preload equivalent to one-half the restoring torque, thus having the total restoring torque, did not correct the problem.

It was determined that, near the start of return rotation, where binding occurred, the area of contact between the star wheel and the driver was extremely small, resulting in very high unit loading at that point. This was enough to inhibit the necessary sliding motion; thus, rotation of the Geneva could not continue.

Solution

The problem was corrected by a modification to the Geneva driver. Rollers were inserted in the driver at the points of high unit loading to eliminate the frictional bind condition. This modification is illustrated in Figure 9 along with a segment of the Geneva operating sequence. With the fiber-optics rope installed no binding in the mechanism occurred and it continued to operate without malfunction throughout the flight program that followed.

FIBER-OPTICS ROPE

Background

A fiber-optics rope was selected to be the optical link connecting the turret and display modules. This approach was selected to minimize transmission of vehicle vibration to the stabilized optical turret.

The fiber-optics rope used in this application is 25 mm in diameter and contains approximately 3 million flexible glass optical conduits (single fiber elements) each 10μ in diameter. The rope length is 7 ft.

In use, an image is focused at the input surface of the rope, with each of the 3 million fibers "seeing" a discrete segment of the image, or picture element. Each fiber acts analogous to a wave guide, wherein the entering rays will be reflected off the sides of the fiber and conducted until it appears imaged at the other end of the fiber. Each glass fiber is clad with a glass coating approximately 1μ thick and having a lower refractive index than the core glass. This cladding functions to maintain a high reflectance (near total) at the side of the fiber, thus minimizing end-to-end losses in the fiber.

The fabrication of the rope is illustrated in Figure 10. The processing provides for the necessary end-to-end coherence in the two-dimensional arrangement of all glass fibers. This arrangement is necessary if the image at the rope exit is coherent with or duplicates the image at the input to the rope.

The fiber-optics rope provides a flexible link that can optically transmit an image over several feet with excellent resolution.

Problem

In the design of the turret module, the mechanization of the optical path (rotating mirrors, etc.) resulted in an unwanted image and horizon rotation. A usual method used for correction of image rotation is the insertion of a rotating Dove prism in the optical path. This prism when rotated will cause the image to rotate. Because of size and weight constraints, a prism could not be installed without seriously compromising optical performance.

Solution

The problem was approached by utilizing the flexibility of the fiber-optics rope, which permits the rope to be twisted about its optical path. With the ends being structured coherently, rotation of one end of the rope relative to the other will cause a rotation of the image at the output end of the rope.

By mechanizing one end of the rope (in this system, the input end was chosen, for convenience) to rotate in response to those parameters which cause image rotation, the rotation which appears at the input to the rope will be corrected or "taken out" at the other end of the rope. With the fiber-optics rope output connecting to the display module, no image rotation will appear in display.

DIFFERENTIAL MECHANISM

Background

Rotation of the fiber-optics rope required a mechanism capable of summing the variables that affect image rotation. These variables are turret azimuth and elevation scan positions and position of the switching mirror (selecting 1X or 7X objective lens). The following outlines the required relationship between rope rotation and the above variables.

Angular rotation of rope must track angular rotation of turret during azimuth scan, maintaining the same angular displacement both in magnitude and phase. The magnitude and phase of this rotation is 0° to 180° clockwise, as viewed from above.

Angular rotation of the rope in response to switching mirror position is the same as for azimuth scan except the magnitude and phase are 120° counterclockwise from 1X to 7X position, also as viewed from above.

Elevation scan from horizon to 75° negative requires a like magnitude of rope rotation. The phasing of rope rotation is where the problem developed.

Problem

In establishing the relationship between elevation scan and image rotation the optical system was evaluated on the basis of viewing through the 1X objective lens. In this situation, elevation scan from horizon to negative 75° requires a clockwise rotation of the rope (viewed from above) for proper phasing. In the initial appraisal, the same relationship appeared to exist for viewing through the 7X objective lens. It was on this basis that the mechanism design was established. (Details of the mechanization will be discussed later.)

During testing of the turret module (as viewed through the 1X lens), the differential mechanism had summed the variables as intended and there was no image rotation. Upon switching to 7X viewing, the problem appeared. Elevation scanning resulted in image rotation. A reassessment of the conditions revealed that, when viewed through the 7X lens, the relationship between elevation scan and rope rotation was 180° out of phase although proper in magnitude. Summarizing, an elevation scan for horizon to negative 75° requires a clockwise rope rotation (viewed from above) for 1X viewing and a counterclockwise rope rotation for 7X viewing.

Solution

This situation was corrected by supplementing the existing design with a phasing mechanism with an output equal in magnitude to the input but either in phase or 180° out of phase, depending upon a second variable, switching mirror position, i.e., 1X or 7X viewing.

Implementation of the modified differential mechanism is described as follows. The phasing mechanism, input-coupled to the elevation heads, drives one input of a geared differential. The other differential input is coupled to switching mirror position (1X or 7X). The outputs of the differential and azimuth scan positions are summed in a second geared differential with its output driving the fiber-optics rope to the proper angular position.

The phasing mechanism itself operates in the following manner. The input shaft drives a pair of mechanical stops. These stops, driven differentially, rotate in opposite directions (out of phase) and in angular magnitude equal to the mechanism input, elevation head position. The output shaft and coupled tab are driven by a DC torquer in either direction, maintaining the tab in contact with either stop depending upon whether an in-phase or out-of-phase output is required (corresponding to 1X or 7X viewing).

Subsequent testing of the turret module disclosed that the modified mechanism successfully combined all influencing variables and corrected image rotation under all circumstances encountered during ground and flight testing.

CONCLUSIONS

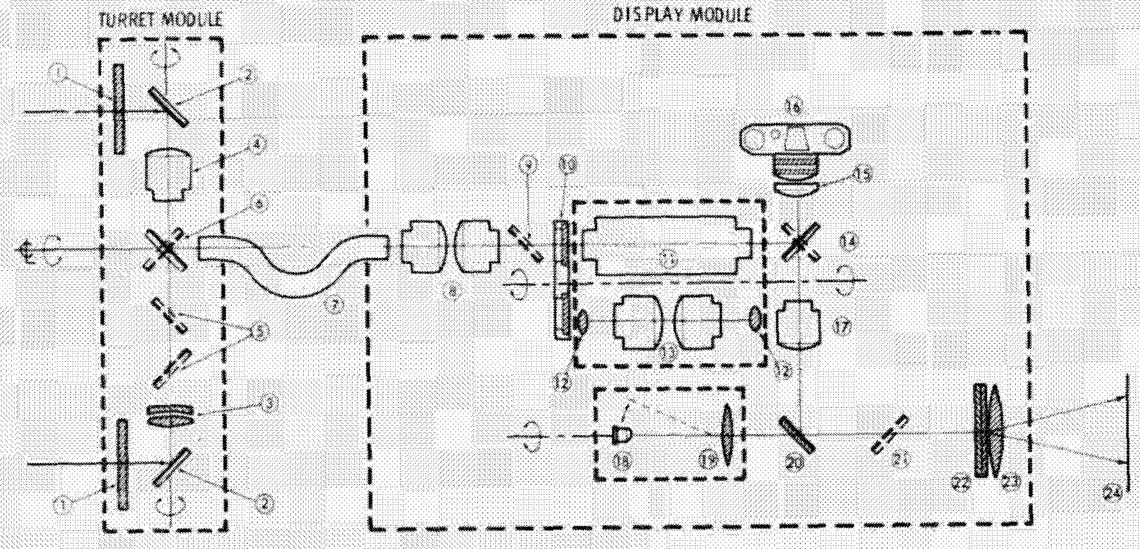
The Helicopter Visual Aid System described in this text has been built an(flight-tested by the Los Angeles Police Department in situations representative of actual flight missions. The mechanisms discussed contributed greatly to the successful performance of the System throughout the 160 hours of flight testing.

It has demonstrated that the visual aid concept can provide improved daytime visual capability, greatly improved nighttime capability, surveillance fror greater distances and/or altitudes, covert operation at night through the use of the IR searchlight, and a photographic recording at the scene being viewed.

A proposal is being prepared, seeking funding for continuation of activity in this area.

REFERENCE

1. Baisley, R. L., Helicopter Visual Aid System, Vols. I and II. Document 650-155, Jet Propulsion Laboratory, Pasadena, California.



1. TURRET WINDOWS
2. TURRET TURNING MIRRORS
3. 21 in. FOCAL LENGTH OBJECTIVE
4. 2 in. FOCAL LENGTH OBJECTIVE
5. TURRET FOLDING MIRRORS
6. TURRET SWITCHING MIRRORS
7. FIBER OPTICS ROPE
8. RELAY LENS PAIR #1
9. DISPLAY TURNING MIRROR #1
10. FILTER WHEEL
11. IMAGE INTENSIFIER
12. FIELD LENSES
13. RELAY LENS PAIR #2
14. DISPLAY SWITCHING MIRROR
15. CLOSE FOCUS ATTACHMENT LENS
16. 35mm STILL CAMERA
17. PROJECTION LENS
18. LIGHT EMITTING DIODE
19. POSITION INDICATOR PROJECTION LENS
20. COMBINING MIRROR
21. DISPLAY FOLDING MIRROR
22. PUPIL SPLITTER
23. VIEWING FIELD LENS
24. EXIT PUPIL PLANE

Figure 1.- Visual aid optical block diagram.

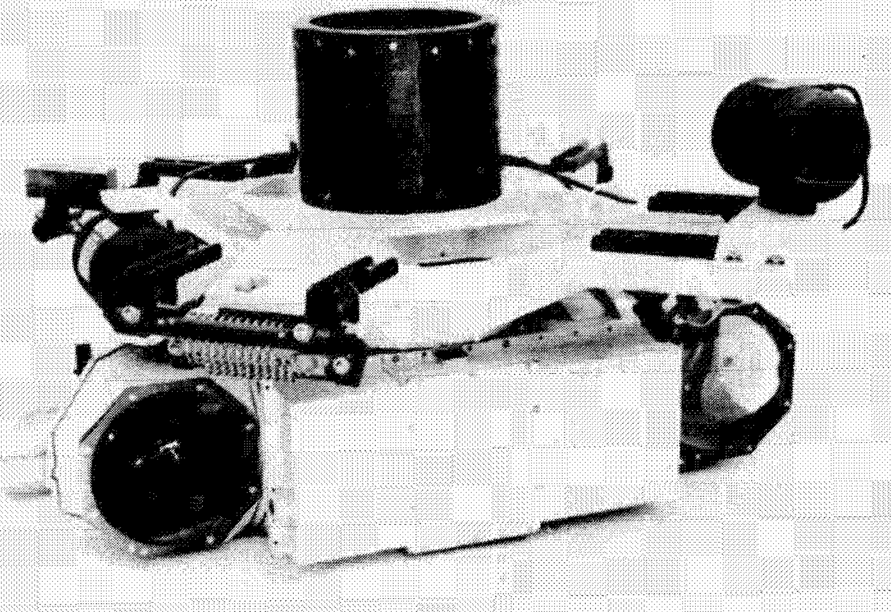


Figure 2.- Turret module.

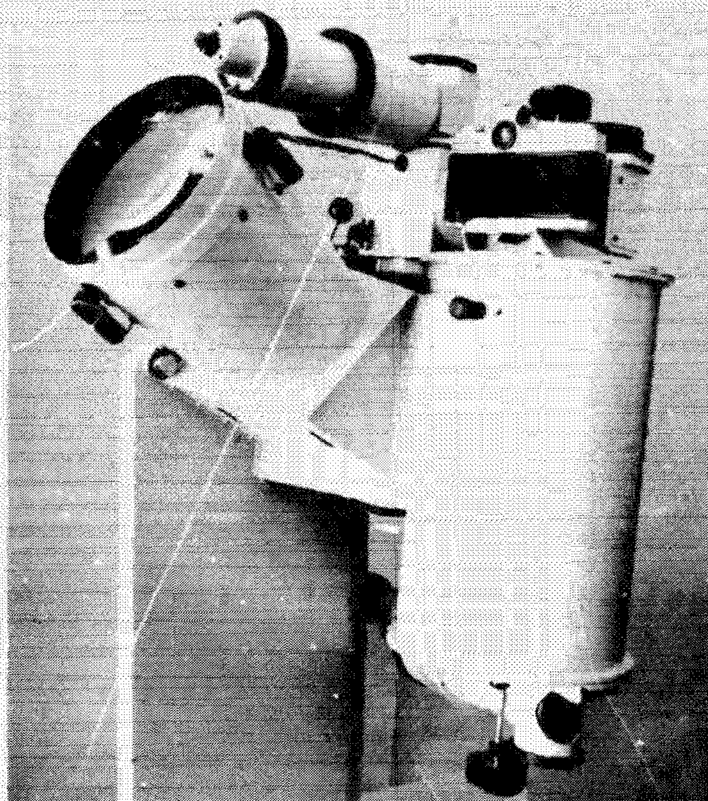


Figure 3. - Display module.

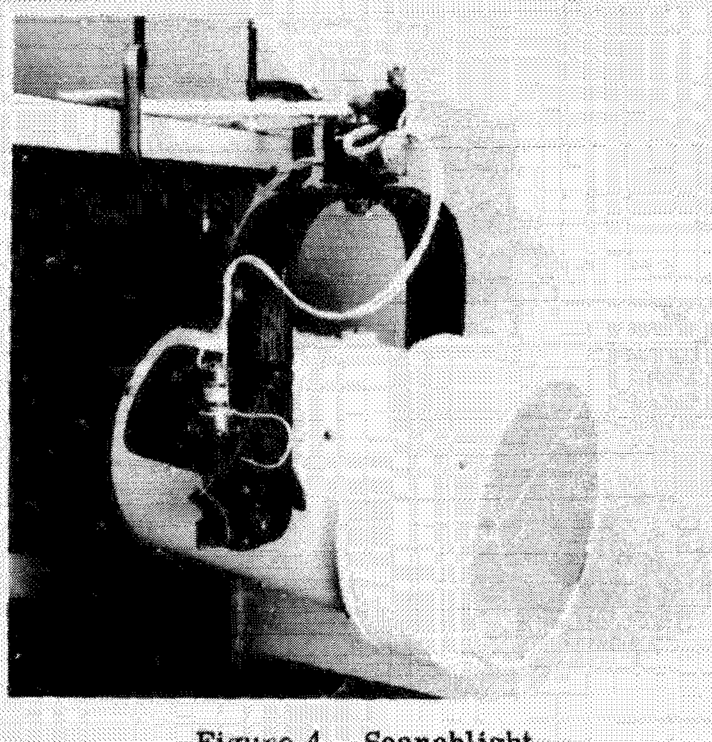


Figure 4. - Searchlight.

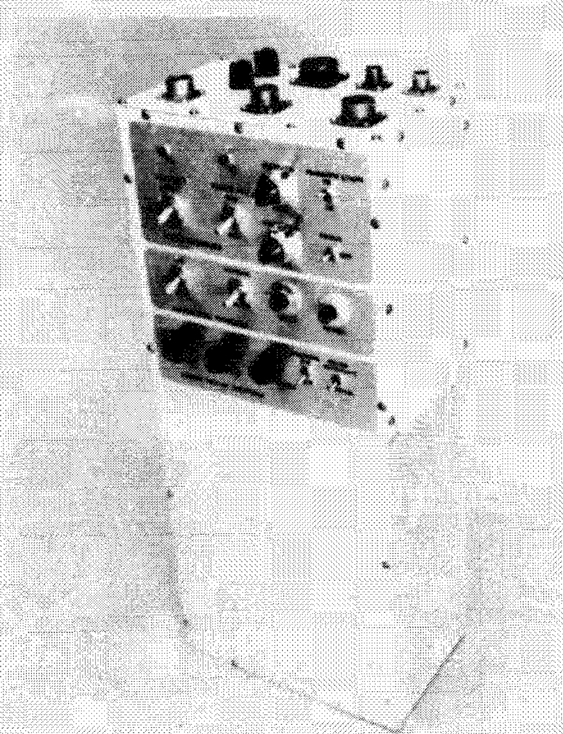


Figure 5. - Control console.

Figure 6. - Helicopter installation.

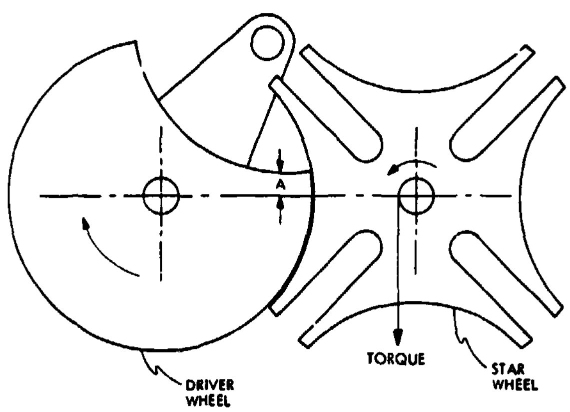


Figure 7. - Geneva mechanism.

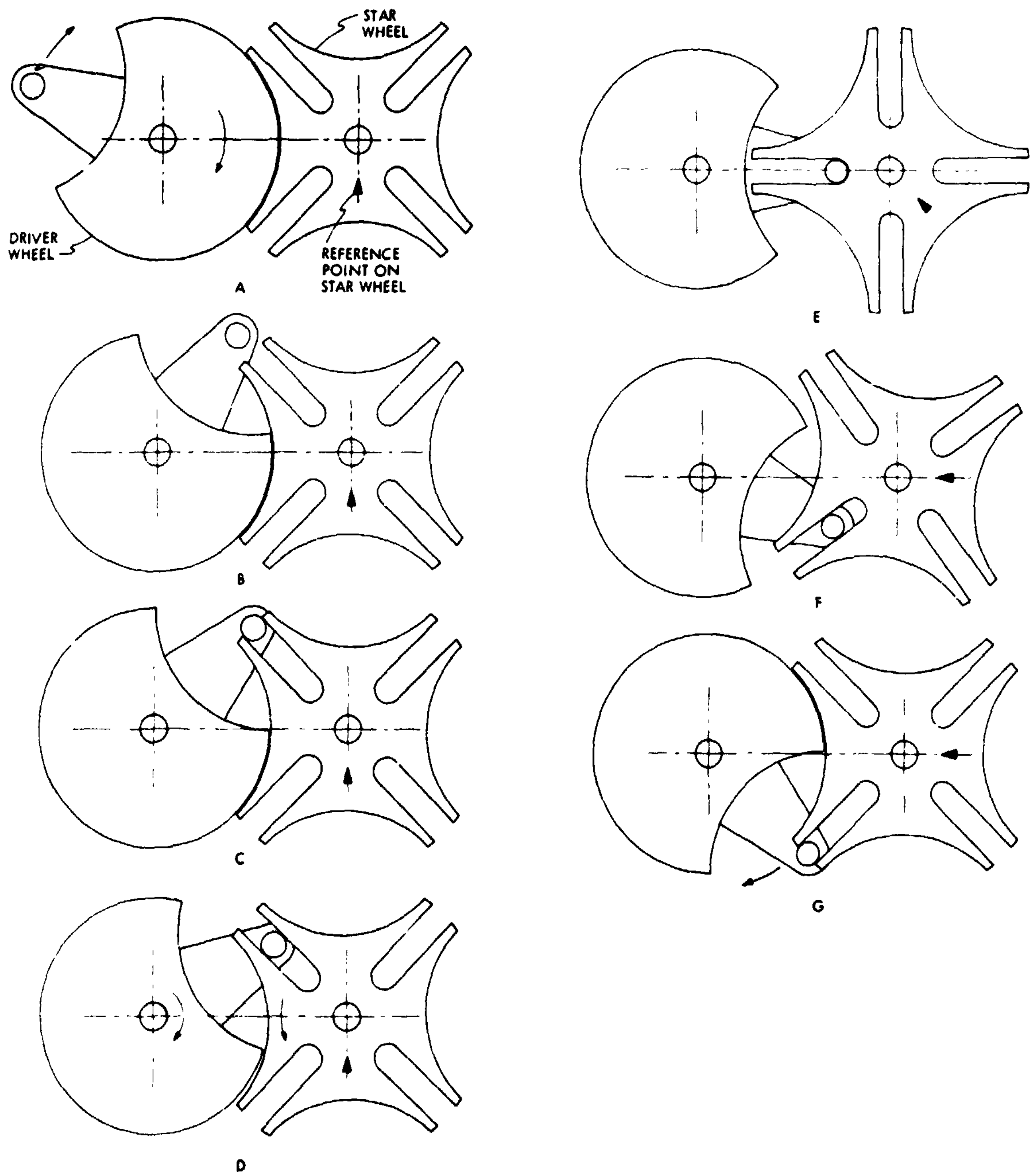


Figure 8. - Geneva operating sequence.

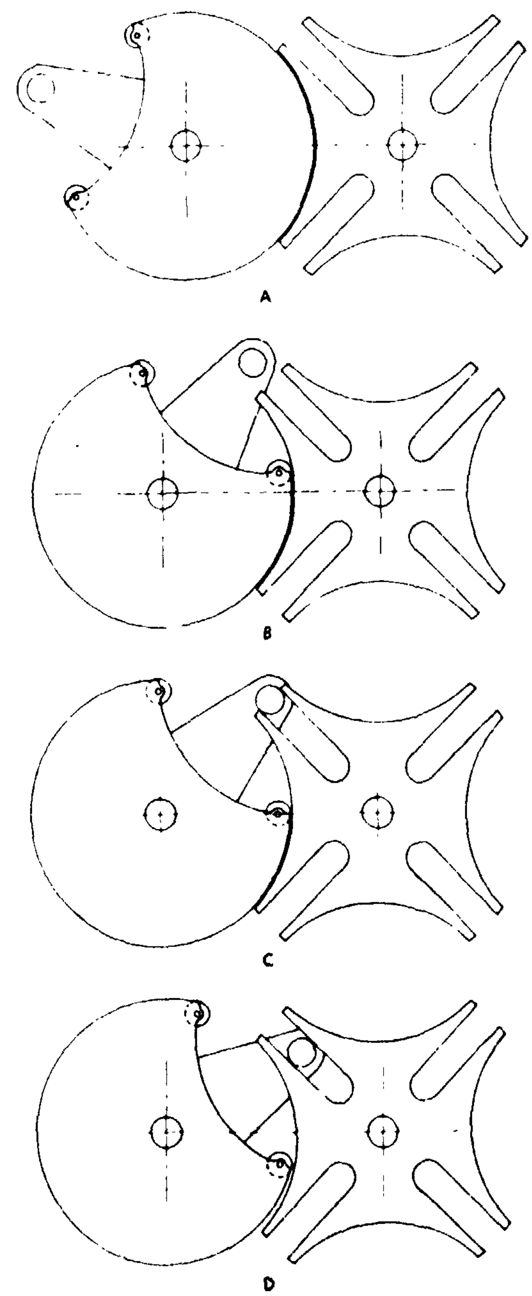


Figure 9.- Modified Geneva mechanism and operating sequence.

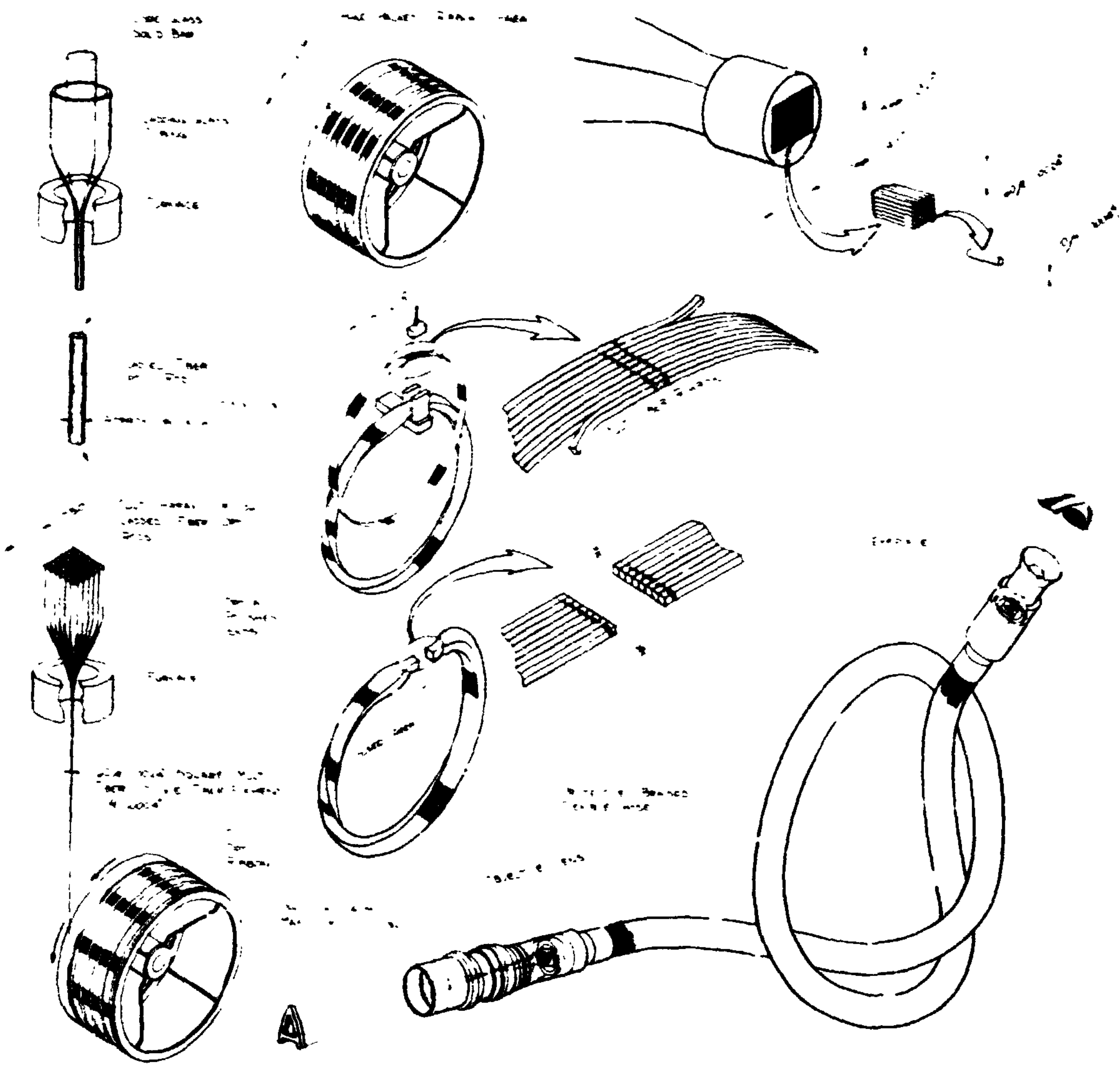


Figure 10.- Fiber-optics rope and fabrication process.